Compound quantitative ultrasonic tomography of long bones using wavelets analysis

Philippe Lasaygues

COMPOUND QUANTITATIVE ULTRASONIC TOMOGRAPHY OF LONG BONES USING WAVELETS ANALYSIS

Philippe Lasaygues
Laboratoire de Mécanique et d'Acoustique, UPR CNRS 7051, 31 chemin Joseph AIGUIER 13402 Marseille cedex 20

Abstract: Compound Quantitative Ultrasonic Tomography (*CQUT)* is used to long bones imaging. We showed that an iterative tool might be used to provide, from reflection tomography, qualitative images of the shape of the object, and to provide, from transmission tomography, quantitative images of the velocity map. Both tomographies are based on ultrasonic propagation in bones, particularly perturbed by this high-contrasted heterogeneous medium. Reflected and transmitted signal are composed of several packages of waves. We propose a novel algorithm based on the wavelet analysis tool adapted to ultrasonic signals that allow the transmitted signals to be cleaned and filtered and the useful information to be separated from the unwanted noise.

Key words: Ultrasonic tomography, bone imaging, wavelets analysis

1. INTRODUCTION

Quantitative ultrasonic tomography is used to long bones imaging. In previous works, we showed that an iterative tool might be used to provide, from reflection tomography, qualitative images of the shape of the object, and to provide, from transmission tomography, quantitative images of the velocity map. Both tomographies are based on ultrasonic propagation in bones, particularly perturbed by this high-contrasted heterogeneous medium. Reflected and transmitted signal are composed of several packages of waves, which had followed various pathways within the cortical shell of long bones. Signal and image processing have a large important part in the complete process.

Transmission tomography is based on the knowledge of the Time-Of-Flight (TOF) measured on the extracted ultrasonic signal and related to the useful velocities of the ultrasonic waves throughout the shell. To optimise our TOF detection processing, we propose a novel signal processing based on the wavelet analysis adapted to ultrasonic signals that allow the transmitted signals to be cleaned and filtered and the useful information to be separated from the unwanted noise.

2. COMPOUND ULTRASONIC TOMOGRAPHY

Ultrasonic Tomography (UT) is based on a linearization of the inverse acoustic scattering problem. It allows perturbations (theoretically small) of a reference medium to be visualized.

For long bones, the acoustic impedance of the cortical is highly contrasted compared to the surrounding soft tissues (or water), and so, perturbs ultrasonic propagation (refraction, attenuation and diffraction). Therefore, bone imaging is a non-linear inverse problem with no single solutions. However, for some hypotheses (weak heterogeneous medium, straight lines waves propagation) and *a priori* knowledge of the analyzed bones, we showed that one solution is possible [1].

Our algorithm combines two tomographies, Ultrasonic Reflection Tomography (URT) and Ultrasonic Transmission Tomography (UTT). URT [2] provides the realistic shape of the bodies and UTT is especially adapted to mapping local velocities inside the area defined. On the final image, the mean geometrical and acoustical parameters may be measured and used to improve the dimensioning and the quantification, ensuring, the complete iterative Compound UT in which the behaviour and the convergence are excellent.

Long human bones are effectively irregular hollow tubes (Figure 1) and should support the propagation of more complex waves similar to elastic volume waves.

Close to the external water/bone interface, the wave is deviated from its initial position because of the refraction throughout the shell. The corrections of this refraction are based on the knowledge of the dimensions and on a velocity ground level (Snell-Descartes laws).

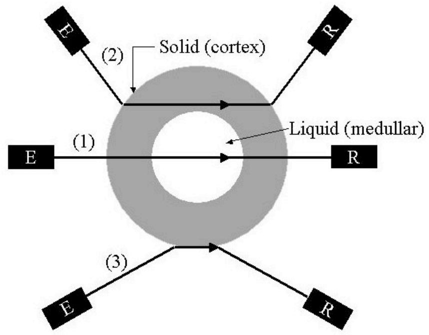

Figure 1. Supposed pathways of the wave propagation throughout cortical long bone for CQUT

3. WAVELET ANALYSIS OF TRANSMITTED SIGNALS

For transmission tomography, projections must be constructed from determination of the TOF between both transducers. The experimental ultrasonic acquisition protocol enabled us, according to the compensation procedure, to digitize correctly the transmitted signals [3], composed of several packages of waves which had followed various pathways within the object (cortex and/or medullary and/or cortex) [4].

Various algorithms of existing *T.O.F.* measurements are based on various definitions of transit times of pulse, such as zero-crossing or thresholding. Our algorithm was based on detecting the arrival time of the signal corresponding to the wave propagating at, or close to, the longitudinal velocity within the shell ("fluid" modeling).

The level of the detection accepted for each signal was fixed by a subjective threshold. Then, the number of bad *T.O.Fs* detected increased because these thresholds are very sensitive to the signal-to-noise- ratio (SNR), and are not correctly adapted to all the values (usually 15^6 or 20^6) that we had to automatically treat. Indeed, the choice of the lower limit of the threshold was fixed for each view angle in relation to the noise. If we extracted the useful signal from this noise and if we standardized all the packages with a criterion which did not perturb their temporal position, the errors decrease.

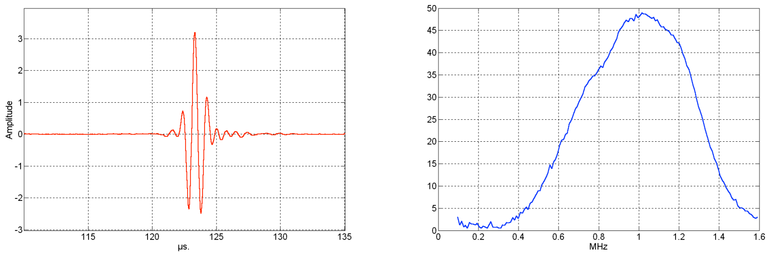

Figure 2. Transmitted signal in water

Our idea was to exploit wavelet analysis, which allowed simultaneous joint studies in the time and frequency domains.

Two aspects were considered in particular: the significant spectral bandwidth of the emitted signal; that is, the transmitted signal without the object (Figure 2) and the axial resolution of the transducer, brought back to the support of this emitted signal. Then we defined a Region-Of-Interest (*R.O.I.*) consisting of this time and frequency bandwidth for the wavelet analysis, filtering and synthesis (sum of the wavelet coefficients).

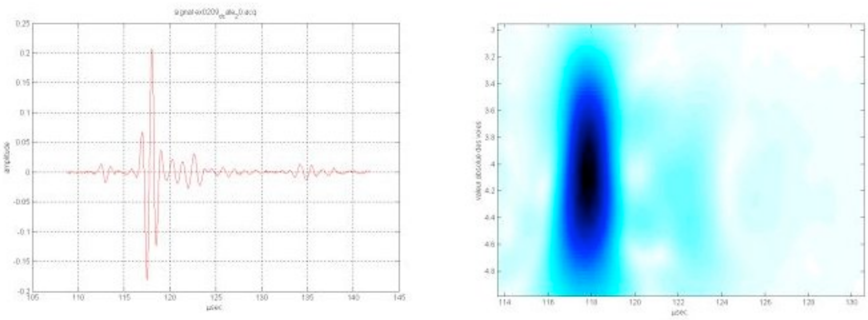

Figure 3. Wavelets analysis of a transmitted signal through the medullary hollow zone (Zone 1)

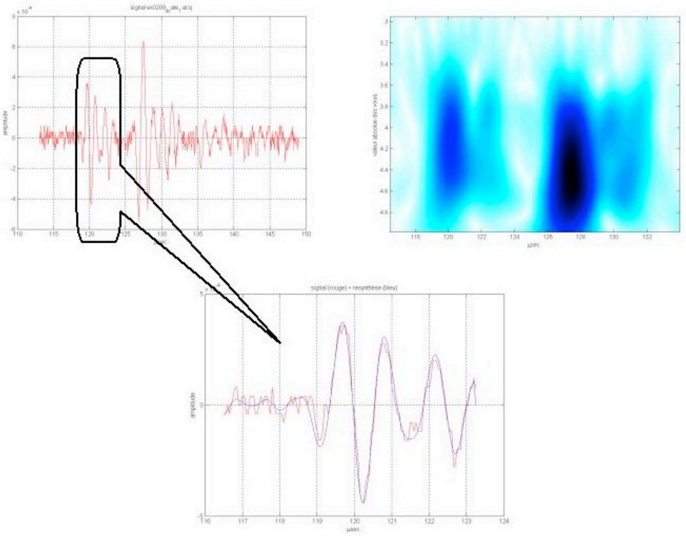

Figure 4. Filtering the transmitted signal corresponding to the wave propagating close to the boundary bone/water (zone 3)

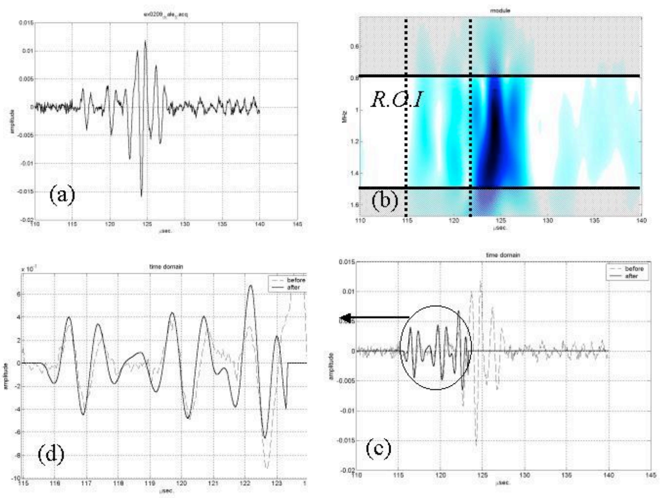

Figure 5. Filtering transmitted signals in solid cortex area (zone 2) (a - temporal representation; b - wavelet decomposition – modulus – and visualization of the R.O.I. on the bandwidth [0.8 - 1.5] MHz (at –25 dB) X [115 – 123.35] μs; c - comparison between the initial signal and its synthesis on the R.O.I.; d – zoom, the SNR and the resolution of the first-arriving signal increase.)

In the medullary hollow zone, the processing of the signals is generally easy and the *T.O.F.* are calculated with a margin for error lower than 2% (Figure 3). In the solid cortex (Figure 4 & 5), signals are much more disturbed.

For example, on the Figure 5, three lots of waves were distinguished with different amplitudes and the first-arriving signal was the lowest and the arbitrary first-time could be 115 μs. The upper signal arrived in water after the *T.O.F.* (123.35 μ*s*) and so, did not correspond to a direct propagation inside the shell.

This signal was analyzed and the *R.O.I.* was defined. Figures 4-d display the curves after filtering. The SNR was higher than before processing, and the signal was filtered for low and high frequencies. The resolution and the quantification of the first two packages had improved.

Hence, the *T.O.F.* detections increased and the false values decreased. The same threshold can be used for all filtering signals for all view angles. The advantage of our algorithm was that the noise reduction, the thresholding and the *T.O.F.* detection could be made simultaneously on the image of the wavelet coefficients.

4. CQUT OF FEMUR

The human sample was a femoral specimen of approximately 32 ± 5 mm for the external diameter and 16 ± 2 mm for the internal diameter. The *a priori* mean-velocities were 3400 m/s in bone and 1478 m/s in water. In previous studies, the femur was compared to a circular tube, but this approximation (Figure 6-left) was not suitable enough. Figure 6-right displays the final image obtained by CQUT.

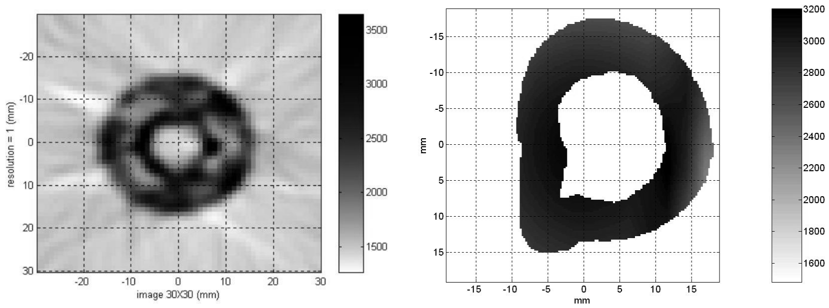

Figure 6. Human femur CQUT, without (left) and with(right) signal processing

The fluid in the internal shape was reconstructed with a correct velocity value (≈ 1500 m/s) and the dimension of this cavity was 15 – 17 mm. The greatest external shape (30 – 34 mm) was exact and the mean-velocity estimated in the cortical shell was 3150 m/s.

5. REFERENCES

[1] Ouedraogo E., Lasaygues P., Lefebvre JP., Gindre M., Talmant M. and Laugier P., Contrast and velocity ultrasonic tomography of long bones, Ultrasonic Imaging 24, (2002) 135 – 146.

[2] Lasaygues P., Lefebvre JP., Cancellous and cortical bone imaging by reflected tomography, Ultrasonic Imaging 23, (2001) 55-68

[3] Ouedraogo E, Lasaygues P, Lefebvre J.P., Talmant M, Gindre M., and Laugier P., Multi-step compensation technique for ultrasound tomography of bone, Acoustical Imaging, 26, (2001), 153-160

[4] Ouedraogo E. 2002 Caractérisation géométrique et Acoustique des os long par tomographie ultrasonore, *Ph.D Thesis* University of Cergy-Pontoise